In this issue:
A new REE mineralisation style
Tungsten mineralisation at Watershed, NE Qld
EGRU 2019 Professional Geologist Short Course Series

Economic Geology Research Centre
College of Science and Engineering
James Cook University
Townsville, Queensland
Australia

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EGRU Contacts

Professor Paul Dirks
Tel: 61 7 4781 3630
Email: paul.dirks@jcu.edu.au
Associate Professor Carl Spandler
Tel: 61 7 4781 6911
Email: carl.spandler@jcu.edu.au

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NW QLD Magma Fertility Project
Professor Paul Dirks
Email: paul.dirks@jcu.edu.au
Geita Gold Project, Tanzania
Professor Paul Dirks
Email: paul.dirks@jcu.edu.au
Adamantine Energy & Heritage Oil Projects
Associate Professor Eric Roberts
Email: eric.roberts@jcu.edu.au
Rare Earths Project
Associate Professor Carl Spandler
Email: carl.spandler@jcu.edu.au

EGRU Services

Upcoming Events: Sn-W-Critical Metals Conference
EGRU Facilities, Equipment and Analytical Capabilities

In This Issue

Director’s Report

Research
Research Staff & Projects
International Collaboration
Unconformity-related REE mineralisation, northern Australia
The Watershed tungsten deposit, northeast Queensland

People
Vale Pat Williams
Postgraduate Research Projects

Field Trips & Conferences
EGRU @ RFG2018
Mineral Systems field trip, Cloncurry Region, July 2018
Minesite Rehabilitation student field trip, Mt Leyshon, NE Qld

Professional Geologist Short Course Series
Preliminary Program
Ore Textures and Breccias Recognition Techniques
Core Logging Techniques
QAQC for Mineral Exploration & Beyond
Integrating Geochemistry & Mineralogy for Exploration
Management in Mineral Exploration: one-day modules
QGIS for Geologists
A JORC Code Refresher
Assessing and Communicating Geological Uncertainty & Risk
Advanced Field Training

EGRU Members

Information about EGRU Membership Levels and Member Benefits is available from the EGRU web site, or contact Judy Botting, EGRU Administration Officer.
Enrolments 3rd Yr - 3 year lag
by industry experts. As exploration activity is starting
skills such as GIS, we have opted for a series of courses
as well as current honours and masters students (see
be of use to recent graduates now working in industry,
period in which EGRU will offer short courses that will
short course offerings addressing these skills and more.
To illustrate that our JCU courses are relevant to the
activities to India and china.
To illustrate that our JCU courses are relevant to the
mining and exploration industry, have a look at the
graph below, put together by Kaylene (EGRU Manager),
which plots annual exploration expenditure in Australia
against total enrolments in 3rd year earth sciences
courses at JCU. The student enrolment numbers have
been shifted backwards by 3 years, to better illustrate the
close relationship between enrolments and exploration
investment. It is clear from this graph that over the
years the minerals industry has been a strong influence
to heat up again we believe these courses will be of use
to industry, and we encourage everyone to take note.
Apart from the short courses, we have also started
in earnest with the organization of an international
conference focused on “St-W-Critical Metals &
Associated Magmatic Systems” to be held in June 2019,
on the Atherton Tablelands. With the rise of demand
for metals used in alternative energy supplies and technology, the focus on tin, tungsten and critical metals is
in the spotlight, and we are excited to announce that
EGRU has already secured a stellar line-up of world
experts as keynote and invited speakers.
So what else is new? Earlier this year, the College of
Science & Engineering at JCU launched its new masters
by coursework programme called the Masters of Science
(professional). Geology is one of the majors in the MSc.
The course has been designed to provide students who
have a general background in science or engineering
with a pathway into geology. We believe that this course
will appeal to international students and with this in
mind we have ramped up our international engagement
activities to India and China.
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investment. It is clear from this graph that over the
years the minerals industry has been a strong influence
on students enrolling in earth science at JCU. It is also
good to note that exploration expenditure has passed the
value of 3 billion, which can only mean that we can look forward to a rise in student numbers – a
trend already visible in first year enrolments. This is,
of course, of great importance to ensure Geology JCU
and, by extension, EGRU, stay vibrant and active.
This newsletter contains reports of a selection of research
activities, field trips and analytical work conducted
under the aegis of EGRU. Final reports from EGRU’s
collaborative NE Queensland Prospectivity Project
were submitted to the GSQ late last year, and a sample
of the results is included in the article on the Watershed
tungsten deposit on page 15. Following completion of
the NE Queensland project, EGRU developed a major
research effort on characterising and assessing the
role of felsic and mafic intrusions on mineralisation
patterns in the Mary Kathleen Domain of the Mt Isa
district in NW Queensland. This project is sponsored
by the Queensland Department of Natural Resources
and Mines through the GSQ, and involves collaboration
with a range of mining companies exploring around Mt
Isa, as well as collaboration with UQ and CODES. The
project is linked to detailed studies of the Tick Hill and
Dugald River deposits, as well as regional work on the
Tommy Creek block, as we are assembling a growing
team of PhD and Honours students to conduct the
work.
The Queensland government is, of course, concerned
about the future of the Northeast Queensland Minerals Province and keen to support innovative
exploration activities in the area, including research.
This is something we hope EGRU can build on as we
are developing new projects such as characterising
source areas for mineralisation by using Cu and Fe
isotopes. As part of our ongoing activities in the Mt Isa
area, this year EGRU again organised a workshop on
Mineral Systems in the Cloncurry Region, to promote
discussion and data exchange amongst explorers and
researchers. This event was held in Cloncurry in March
(a report was included in the April newsletter), but at
the time we were not able to conduct the field trip
because of the heavy rains. Instead, we held the field
trip in late July, with about 30 industry participants
joining EGRU researchers on a visit to the Osborne
mine and nearby prospects, and the Carnmington Mine.
This trip was a great success and was made possible
thanks to generous sponsorship by Chinova and South
32. As a follow up to the field trip, and with support
from Chinova, Ioan Sanislaw and I returned to Osborne
in early September to map the pit in an effort to better
constrain the timing of mineralization, given that the
published age of 1595 Ma for Osborne mineralization
does not quite fit the general picture. More of this in
the next newsletter.
After a great thought we have decided to run the
next EGRU mineral systems workshop in western
Queensland in 2020, when there will be results to
report from new and upcoming research projects.
Several EGRU staff and students (Carl Spandler, Paul
Dirks, Kaylene Camuti, Paul Slezk and Teimoor
Nazeri Dekhordi) attended the inaugural Resources
for Future Generations Conference (RFG 2018) in
Vancouver in June. RFG2018 was organised by
several Canadian geoscience organisations, under the
umbrella of the International Union of Geological
Sciences. The conference was aimed at addressing the
longer-term supply of mineral, energy and water
resources for the next century. In so doing the
conference combined traditional technical talks on
mining, oil, gas and economic geology, with a wide
range of talks, discussion sessions and fora focussed
on the role of natural resources including alternative
energy on the development of future economies and
societies. The concept was new and exciting, although
it sometimes felt that two separate conferences were
taking place under the same roof. However, it has given
us ample food for thought on how to approach the next
FUTORES conference (FUTORES III) conference in
Townsville.
On the analytical front we are happy to announce
that the laser is back up and working well, and we are
pumping out U-Pb dates again. Our work for the NT
geological survey is progressing well, and the new SEM
and Raman spectrometer are proving to be fantastic
tools for students and staff alike.
As always EGRU continues to enjoy presentations
by visitors from industry and academia worldwide,
and we were recently pleased to welcome the SEG
Distinguished Lecturer, Professor Chris Heinrich.
Professor Heinrich, from the Department of Sciences
at ETH in Zurich, visited EGRU after a field trip in the
Mt Isa region. After meeting with research staff and
students, he gave a presentation on Fluid evolution
and the selective metal enrichment in magmatic-
hydrothermal Cu-Au ore systems, to an audience of
researchers, students, and industry geologists.
EGRU values the support of our continuing members
and I would like to thank them for their sponsorship.
EGRU also greatly appreciates the help of all those
miners and explorers out there who continue to assist
our staff and students by supporting our research
and teaching, and by acting as our ambassadors. And
we welcome your suggestions for future short courses and
EGRU activities.
<table>
<thead>
<tr>
<th>Research Staff</th>
<th>Research Projects</th>
</tr>
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<tbody>
<tr>
<td>Prof. Paul Dirks</td>
<td>NE Qld Magma Fertility: Cu-Au, Sn-W</td>
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<td>NW Qld Magma Fertility</td>
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<td></td>
<td>Rare Earths Project</td>
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<td>Geita Gold Project</td>
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<td>Adamantine Energy &amp; Heritage Oil Project</td>
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<td>Conglomerate Hosted Gold</td>
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<td></td>
<td>Tick Hill Gold Deposit</td>
</tr>
<tr>
<td></td>
<td>Jurassic Arc? Reconstructing the Lost World of Eastern Australia</td>
</tr>
<tr>
<td></td>
<td>Porphyry Cu-Au Systems</td>
</tr>
<tr>
<td></td>
<td>Formation of Graphite Deposits in Sri Lanka</td>
</tr>
<tr>
<td></td>
<td>Identifying Hydrothermal Fluids in the Cloncurry District</td>
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<td>Thermodynamic Modelling of Fluids in Hydrothermal Systems</td>
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<tr>
<td></td>
<td>The Role of Fluids in the Lower Crust</td>
</tr>
<tr>
<td></td>
<td>Seismic Stratigraphy and Petroleum Systems of the Mentelle Basin, Southwest WA</td>
</tr>
<tr>
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<td>Establishing a Tectonic Framework for the Cretaceous Break-up of Eastern Gondwana</td>
</tr>
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<td>Stratigraphy and Sedimentary Basin Analysis of Qld’s Jurassic to Cretaceous Basins</td>
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<tr>
<td></td>
<td>Jurassic-Cretaceous Tectonics, Paleogeoography and Landscape Evolution, Central Africa</td>
</tr>
<tr>
<td></td>
<td>Dating hominin fossils in the East African Rift, Malawi</td>
</tr>
<tr>
<td></td>
<td>Seismic Stratigraphy of the Great Barrier Reef</td>
</tr>
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<td></td>
<td>Earthquake Hazard Mapping and Modelling to Support Qld Rail’s Infrastructure</td>
</tr>
<tr>
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<td>Rates of Erosion and Weathering in the Tropics</td>
</tr>
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<td>Groundwater – Ocean Interconnection</td>
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<td>Sedimentary and Magmatic History of the Rukwa Rift Basin</td>
</tr>
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<td></td>
<td>Geochronology of Mineralisation Processes</td>
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<tr>
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<td>Geology of the Tommy Creek Block, Mount Isa Inlier</td>
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<td>A/Prof. Carl Spandler</td>
<td>NE Qld</td>
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<td>NW Qld Minerals Province</td>
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Photos: Robbie Coleman, EGRU JCU
International Collaboration

Prof. Paul Dirks, EGRU Director

The past few months have been busy from the perspective of establishing international collaborations in research and teaching. For several years now, EGRU has been working on deepening its relationship with China University of Geosciences (CUG), Wuhan. In March 2017 we signed a collaborative agreement to accommodate student exchanges at undergraduate level, which was followed up with an invitation for Wuhan students to join our 3rd year undergraduate field trip to Cloncurry. In 2017, three students and a lecturer joined us, and this year we were joined by 10 undergraduate students and their lecturer, Dr. Zhanke Li. At the same time, EGRU has been hosting several visiting scholars from China, including PhD students from CUG.

In preparation for the field trip, and as part of our developing research collaboration I travelled to China for two weeks to deliver a one week short course on Archaean tectonics and associated gold mineralization to students in the College of Earth Resources, and to provide introductory lectures to the students who joined us in Cloncurry. We also discussed research collaborations through the establishment of a joint-PhD programme, and participation of JCU in a large research proposal on “Metallogenic systems related to trans-crustal magmatic and fluid processes” put forward by Prof. Jian Wei Li (Dean of college).

As part of the visit, I joined researchers and PhD students from CUG for a one week visit to some of the major gold mines in the Shandong gold district, mostly owned and operated by Shandon Gold including: Linglong, Dongfeng, Jiaojia, Wangershan and Sanshandao mines and operated by Shandon Gold including: Linglong, Dongfeng, Jiaojia, Wangershan and Sanshandao mines (all major 10Moz plus deposits). All of these mines are on the books as potential orogenic gold deposits, (Quirt et al., 1991; Rabiei et al., 2017). The Maw Zone deposit, which consists of hydrothermal xenotime mineralisation hosted within brecciated sandstones of the Athabasca Basin, Canada (Quirt et al., 1991; Rabiei et al., 2017). The Maw Zone is, however, a relatively small mineral resource and it is unclear whether it is unique, or an example of a regional (or globally) significant mineralisation style for which other deposits are yet to be discovered. Exploration programs for REE deposits, therefore, largely target magmatic systems, with carbonatites, peralkaline silicate intrusions and pegmatites considered to be the most prospective hosts. These rock types are, however, relatively rare in the rock record, so the recognition of additional styles of REE mineralisation is significant for future REE resource security.

In a further effort to boost student numbers in the JCU geology programmes, I joined colleagues from marine biology, engineering and JCU recruitment on a visit to various schools and universities in India towards the end of September. During the first semester of 2018, the College of Science & Engineering launched its new Masters of Science (professional) and Masters of Engineering (professional) programmes. The new MSc programme includes specialisations in Geology and Environmental Earth Sciences, which are ideally suited for international students with a science or engineering background who want to move towards an Earth Sciences career. JCU has identified India and Sri Lanka as potential markets for the course, and we travelled to a number of major cities in India and Sri Lanka and met with Universities, career counsellors and recruitment business owners to promote our courses. There is a clear interest in Economic Geology in India, but careers in mining and exploration are generally not promoted on the sub-continental. The meetings were very encouraging and we hope they will constitute the start of research collaborations and a pipeline of Indian students to JCU.

Unconformity-related REE mineralisation, northern Australia

Teimoor Nazari-Dehkordi (EGRU JCU Geoscience), Carl Spandler (EGRU JCU Geoscience) Nicholas H.S. Oliver (HCOV Global Consultants, JCU), Robin Wilson (Northern Minerals, WA)

Introduction

More than 95% of known Rare Earth Element (REE) resources are hosted within alkaline magmatic rocks and carbonatites, or have genetic links with magmatic rocks (Quirt et al., 1991; Rabiei et al., 2017), and less than 3% of the known global resources are in placer-type deposits. Hydrothermal processes can mobilise and redistribute REE at the deposit scale (Gysi et al., 2015; Migdisov et al., 2016) and there are a number of vein and breccia style REE orefields. For example, the deposits of Steenkampsraal (South Africa), Hoidas Lake (Canada), Nolans Bore (Australia), Gallinas (USA), and Olsemur-Dupedal (Sweden), all have inferred hydrothermal origins. Almost all of these deposits, however, have demonstrable links with magmatism (Williams Jones et al., 2000; Harmer and Nex, 2016; Anenburg et al., 2018). Indeed, it has been suggested that many REE vein deposits, such as Nolans Bore and Hoids Lake, are direct products of wall-rock reaction with carbonatitic rocks, rather than of hydrothermal activity (Anenburg et al., 2018). An exception to this is the Maw Zone deposit, which consists of hydrothermal xenotime mineralisation hosted within brecciated sandstones of the Athabasca Basin, Canada (Quirt et al., 1991; Rabiei et al., 2017). The Maw Zone is, however, a relatively small mineral resource and it is unclear whether it is unique, or an example of a regional (or globally) significant mineralisation style for which other deposits are yet to be discovered. Exploration programs for REE deposits, therefore, largely target magmatic systems, with carbonatites, peralkaline silicate intrusions and pegmatites considered to be the most prospective hosts. These rock types are, however, relatively rare in the rock record, so the recognition of additional styles of REE mineralisation is significant for future REE resource security.

Here we describe HREE+Y mineralisation that occurs as numerous structurally controlled deposits and prospects across a large part of the North Australian Craton, an area henceforth referred to as the North Australian HREE+Y (NAHREY) mineral field. Through the combined application of ore petrology, mineral chemistry, geochronology, and Sm-Nd isotope analysis of a number of these deposits we show that this mineralisation type has no genetic link to magmatism. Instead, it represents hydrothermal mineralisation that formed by REE leaching from the metasedimentary host rocks, under conditions somewhat akin to those proposed for mid Proterozoic unconformity-related U deposits of Australia and Canada, and to that proposed for the Maw Zone (Rabiei et al., 2017). The recognition of this regionally significant HREE+Y mineralisation type expands current definitions of REE ore formation settings and may lead to alternative exploration strategies for identifying new REE resources.

Geological Setting

The North Australian HREE+Y (NAHREY) mineral field extends approximately 300 km from the John Galt REE Deposit in the east Kimberley of Western Australia to the Killi Killi Hills in the Tanami Region (Fig. 1; Vallini et al., 2007). Known mineralisation consists of around 20 deposits and prospects, and is mainly centered on the western side of the ~60 x ~30 km Browns Range Dome in the northwest of the Tanami Region (Fig. 2; Cook et al., 2013).

The Wolverine Deposit is the largest of the known orefields, with a total mineral resource of 4.97 Mt at 0.86% total rare earth oxide (Northern Minerals, 2015), and shares fundamental characteristics with all the other deposits and prospects (e.g., Iceman, Cycllops, Boulder...
Unconformity-related REE mineralisation, northern Australia

Mineralisation Style

The style of mineralisation across the NAHREY field is remarkably uniform and consists of planar orebodies of quartz-xenotime-(Y) veins and breccias hosted in steeply-dipping fault zones (Fig. 4; Cook et al., 2013). The highest-grade mineralisation occurs in chaotic to mosaic breccias consisting of altered and rounded clasts of BRM (<0.1 m) within a xenotime-(Y) rich matrix. The chaotic and mosaic breccia zones are commonly cross-cut and mantled by crackle breccias with networks of crustiform to comb-textured quartz-xenotime veins (Fig. 4B). The ore mineralogy consists only of xenotime-(Y) with subordinate florencite(\(\text{Ce}\)) \([\text{LREE}\text{Al}_3(\text{PO}_4)_2(\text{OH})_6]\). This simple mineralogy is distinctive, as other REE deposits generally consist of highly complex REE mineral assemblages (Weng et al., 2015).

The major mineral assemblages associated with the mineralisation and the host metasedimentary rocks include:
1. a pre-ore detrital and metamorphic assemblage which includes quartz, alkali feldspar and coarse-grained muscovite;
2. a syn-ore hydrothermal mineral assemblage consisting of xenotime-(Y), florencite-(\(\text{Ce}\)), quartz and fine-grained hydrothermal muscovite. The ore minerals are subhedral to euhedral, and are morphologically distinct from the highly pitted and corroded REE phosphates that occur as fine accessory grains in the host BRM.

Hematite is locally abundant in fault zone breccias and veins associated with mineralisation, but mainly predate or postdate xenotime-(Y) formation.

Figure 4: (A) Ore-associated hydrothermal breccias developed along a major fault structure near the Wolverine Deposit. Note the clasts of Browns Range Metamorphic (BRM) within a vein quartz matrix. (B) Drill core sample of pink xenotime-(Y) (Xnt) + quartz (Qtz) crackle veins in the BRM (Wolverine Deposit). The xenotime-(Y) occurs on the margins of the quartz veins. (C) Cut surface of a core sample of a mineralized breccia (Wolverine Deposit) consisting of silicified clasts of BRM within a xenotime matrix (salmon color). Note the post-ore hematite (Hem) vein to the bottom left of the image.
Carbonate minerals are absent, and the syn-ore fine-grained muscovite is enriched in F (up to 0.5 wt. %) compared to the pre-ore muscovite.

Bulk-rock geochemical data from the Wolverine Deposit, collected by Northern Minerals Ltd, reveals most of the BRM (host rocks to the ore) have compositions consistent with a mineralogy dominated by quartz, alkali feldspar (predominantly K-feldspar) and muscovite in variable proportions; this is in agreement with petrographic observations (Nazari-Dehkordi et al., 2017). However, the K/Al bulk rock ratios of almost all the mineralised ore samples are consistent with a bulk mineralogy of muscovite and quartz and, in the absence of newly crystallised K-feldspar to muscovite in alteration zones associated with ore. This alteration, together with the simple REE mineralogy, is a classic indicator of large metasomatic fluid fluxes (Korzhinskii, 1970).

**Timing of Mineralisation**

Previous U-Pb dating of primary xenotime-(Y) from a number of occurrences across the NAHREY mineral field has yielded mineralisation ages of between 1.65 and 1.61 Ga (Vallini et al., 2007; Morin-Ka et al., 2016). Additional U-Pb data on accessory xenotime(Y) from the Wolverine, Cyclops, and Boulder Ridge orebodies was carried out in this study, to further constrain the timing of the HREE enrichment of the mineralised ore samples.

These results are consistent with the previous dating results of Vallini et al. (2007) and Morin-Ka et al. (2016) and indicate a relatively short time frame of xenotime-(Y) mineralisation across the region. The mineralisation age postdates known magmatism in the region but is close in age to the deposition of the Gardiner Sandstone (Vallini et al., 2007). The distinctive signature of HREE+Y depletion of the BRM is not shared by granitic or sedimentary protoliths, but does mirror the REE enrichment signature of the ore.

A similar leaching process has been proposed for hydrothermal mobility of REE in environments of unconformity U deposits (Gaboreau et al., 2007), and is consistent with the results of experimental leaching of sedimentary rocks by acidic fluids (Ohr et al., 1994). In addition to acidic conditions, hydrothermal transport of REE also requires complexation with species such as Cl-, F-, CO$_3$-, and SO$_4$- (e.g., Migdisov et al., 2016; Zhou et al., 2016). While the ore mineralogy at Browns Range does not include carbonate or sulphate, it does include F-rich hydrothermal muscovite and CI-bearing fluid inclusions hosted in quartz (Richter et al., 2018; Nazari-Dehkordi et al., in prep). Therefore,REE leaching of the BRM was likely caused by percolation of low pH saline (Cl, CF) fluids, with potential fluid sources including the metasomatic basement rocks and basinial brines, both of which can have appreciable halogen contents (e.g., Chae et al., 2007; Kharaoka and Hanor, 2014).

After dissolution of REE+Y from the basement metasedimentary rocks, the percolating hydrothermal fluids migrated into fault structures where REE+Y phosphate minerals were precipitated in the vicinity of regional unconformities.

**Ore deposition**

The ore minerals across the NAHREY mineral field are exclusively phosphates. Phosphorous has low solubility in hydrothermal fluids and is considered to be effective in binding with soluble REE to drive mineral precipitation (Williams-Jones et al., 2012; Gysi et al., 2015; Migdisov et al., 2016). The BRM has a low phosphate content so the P required for precipitation probably originated from a different source to that of HREE, and we propose that P was supplied from BRM phosphate sandstones that lie above the unconformity. This unit is reported to contain Fe-stained phosphate (Vallini et al., 2007) and detrital apatite (Craspe et al., 2007), and phosphate dissolution was likely driven by low-pH meteoric fluids circulating through the Birrindudu Group sandstones, as has been reported for other sandstone units (e.g., Morton, 1986).

The P was probably transported in an acidic environment under which P is highly soluble, possibly as HPO$_4$ or H$_2$PO$_4$ (e.g., Migdisov et al., 2016), with acidic fluids carrying REE, with acidic fluids carrying P. Based on these criteria, several prospective areas have been identified in northern Australia and Canada.

**References**

The Watershed Tungsten Deposit, Northeast Queensland

Jaime Poblete1, Zhaoshan Chang1,2, Paul Dirks1 Martin Greissman3, Robert Skreczynsky4, Chris Hall1

1EGRU JCU Geoscience, 2Colorado School of Mines, 3Vital Metals Ltd, 4Brisbane, 5Argon Geochronology Laboratory, University of Michigan

The following is a sample of research carried out as part of the first author’s PhD project. For details, data and a comprehensive discussion of the geology of the Watershed deposit, see Jaime A. Poblete, Zhaoshan Chang, Paul Dirks, Martin Greissman, Robert Skreczynsky, Chris Hall Geoscience Frontiers, v. 7, p. 315–334.

Introduction

Northeast Queensland is host to numerous tungsten, tin and lode-gold deposits. Most of these deposits are hosted within the Silurian-Devonian metasedimentary units of the extensively deformed Hodgkinson Formation, which are intruded by S-type granitic bodies of the Permian Whypalla Supersuite. The Watershed scheelite-vein deposit is located in Far Northeast Queensland (Fig. 1). The main part of the deposit is hosted by undeveloped tungsten deposits in the world, outside of China. Mineralisation largely comprises scheelite in vein systems that typically cut calc-silicate conglomerates of the Hodgkinson Formation (Garrad and Bultitude, 1999). The deposit has a JORC resource of 49.2 Mt at 0.14% WO3; Vital Metals ASX announcement, 4 July 2018 https://www.asx.com.au/asxpdf/20180704/pdf/43w8v96m89wl68.pdf.

Scheelite-bearing tungsten deposits around the world are typically associated with either metamorphic or igneous origins and styles of mineralisation. Scheelite metamorphogenic mineralisation is genetically associated with intrusive rocks (Rundquist and Denissenko, 1986; Wood and Samson, 2000) may develop massive endo- or exo-skarn and/or greisen alteration (Kwak, 1987), depending on the host-rock composition and metal availability (Pirajno, 2009). Scheelite-rich skarns are associated with a reduced environment of formation (Ishihara, 1977; Shimazaki, 1980; Newberry, 1983), and hence have reduced gangue mineral assemblages (Shimazaki, 1977; Shimazaki, 1980; Newberry, 1983). The gangue assemblages are characterised by low-andradite garnet and pyroxene (Meinert et al., 2005) which shows a systematic mineral compositional change towards the source of the mineralizing fluids (Newberry, 1983).

Metamorphic scheelite deposits are unrelated to plutonic activity and form during regional metamorphism in pelitic sedimentary rocks (Tweto, 1960; Derre et al., 1986; Kwak, 1987). In contrast to intrusive-related scheelite skarns, the compositional zonation of metals and gangue minerals in metamorphic deposits is poorly developed or absent (Kwak, 1987). Tweto (1960) considered that metamorphic scheelite deposits required sedimentary host rocks that are enriched in tungsten prior to metamorphism, to allow tungsten to be remobilised and redeposited in response to deformation, in a process similar to lode gold deposits (Pitcairn et al., 2006). Hybrid models have also been proposed, in which scheelite deposits may form through a combination of early magmatic tungsten emplacement and later metamorphic remobilisation with localised enrichment (Fontellels et al., 1989; Thalhammer et al., 1989).

Around 60 tungsten-dominated mineral occurrences have been identified in the Hodgkinson Formation in the vicinity of the Permian Whypalla Supersuite (Geological Survey of Queensland database, 2017). The most significant deposits are Watershed and Mount Carbine (de Roo, 1988), along with the abandoned Mt Perserverence mine, which has similarities to Mt Carbine and was mined in the 1960s (de Keyser, 1961). Mt Carbine shares some geological similarities with Watershed, such as a similar vein style of mineralisation, and a similar mineral paragenesis. Differences between Watershed and Mt Carbine include different ore mineralogy (scheelite versus wolframite), and different host rock and alteration (calc-silicate versus chloride-ilite alteration) (Chang et al., 2017).

Many of the tungsten-rich deposits in Far North Queensland have been linked to intrusive rocks (Bateman, 1985; de Roo, 1988). However, as mentioned above, scheelite deposits can occur as both intrusive-related and metamorphic deposits, and it is important to understand the geological factors that constrain the scheelite-rich veins at the Watershed deposit. This study of the mineralisation at Watershed was aimed at developing a model for the origin and evolution of the Watershed tungsten deposit, and defining the principal controls on mineralisation. The study involved the collection of:

- Detailed geological information to constrain the relationship between deformation events and scheelite mineralisation.
- Mineral chemistry data to understand the fluid evolution at Watershed and investigate if the calc-silicate mineralogy exhibits compositional trends indicative of an intrusive source.

1) Sarow, A. R., and Wiltz, M. T., 2010. Ar–Ar muscovite geochronology from veins and vein halos, and U/Pb zircon geochronology from intrusive rocks to constrain the age of deformation and mineralisation in the Watershed area.
Exploration History

The Watershed deposit was discovered in 1979 by Utah Development Company during regional exploration. From 1980 to 1984 Utah delineated the Watershed deposit and also discovered three more tungsten prospects immediately south of Watershed (Watershed South, Desailly North and Desailly). In 1984, BHP Billiton acquired Utah and entered into a joint venture agreement with Peko-Wallsend Operations Ltd (GeoPeko) to carry out exploration at Watershed. Exploration began in 1985 and continued until the tungsten price dropped during the second half of the 1980s; following the fall in price no significant work was carried out at Watershed for twenty years.

Vital Metals Ltd. purchased the Watershed project from BHP Billiton in 2005 and conducted a program of exploration and development from 2005 to 2018. Following a 2012 joint venture agreement with the Japan Oil, Gas, and Mineral National Cooperation to earn 30% of the deposit, Vital Metals carried out over 40,000m of diamond and RC drilling, and a feasibility study in 2014 proposed a 2.5 Mt per year open pit operation with a ten year mine life. In July 2018 Tungsten Mining NL (TGN) acquired a 100% interest in the Watershed tungsten deposit for $15 million cash. At the time of purchase the project was operating under care and maintenance awaiting an increase in the tungsten price.

Regional Geology

The Watershed deposit is located in the Mossman Orogen, an extinct, active margin system that, in the north, abuts the North Australian craton along the NNW trending Palmerville Fault (Fig. 1). The Mossman Orogen comprises the Siluro-Devonian Hodgkinson and the Broken River Provinces, and mainly consists of multiply deformed sedimentary successions that were deposited mainly in a deep-marine environment (Henderson et al., 2013). The Hodgkinson and Broken River Provinces form a belt 500 km long and up to 200 km wide, that is fault-bounded by the Charters Towers and Barnard provinces of the Thomson Orogen to the south and southeast, respectively. Rocks of the Hodgkinson Province are interpreted to have formed in a fore-arc system with the intrusive rocks of the Siluro-Devonian Pama Igneous Association to the west (Fig. 1), representing a contemporary magmatic arc (Henderson et al., 2013).

The Watershed deposit is hosted by units of the Hodgkinson Formation. The Hodgkinson Formation comprises alternating sandstone-mudstone beds with turbiditic affinities that are locally interbedded with greywacke and quartz-greywacke units and rare intercalated beds of chert, volcanic rocks, limestone and polymictic conglomerate (Amos, 1968; de Keyser and Lucas, 1968). The Formation has undergone intense deformation with associated regional metamorphism and, while the deformation histories proposed by different workers vary in detail (Bateman, 1985; Davis, 1993; Peters, 1993; Davis and Forde, 1994), there is consensus that, on a broad scale, there have been at least four discrete regional deformation events (D1 to D4; Davis, 1993; Henderson et al., 2013).

D1 events are Devonian in age and coincide with peak-metamorphism at low- to mid-greenschist facies in the southwest, grading to upper-greenschist facies in the northeast of the Hodgkinson Formation. D1 events are Devonian in age and coincide with peak-metamorphism at low- to mid-greenschist facies in the southwest, grading to upper-greenschist facies in the northeast of the Hodgkinson Formation.
commonly represented by a bedding-parallel slaty cleavage and variable plunging, mesoscale isoclinal folds. A rock type referred to as “broken formation” (Wood, 1982) or “melange” (Henderson et al., 2013) is widely developed in the Hodgkinson Formation, and occurs in up to 5km wide zones with gradational contacts to coherent strata. The formation of these deformational zones has been linked to D2.

D2 is also regarded as province wide and related to large-scale folds with wavelengths of several kilometres, which formed during Devonian to early Carboniferous compressional events (Henderson et al., 2013).

The intrusions in the area of the Watershed deposit are represented by ~4,000 km² of outcrop of mainly Permian S-type and minor I-type granites assigned to the Daintree Subprovince (Mckenzie and Wellman, 1997). The intrusive rocks in the central part of the Hodgkinson Province were emplaced along a northwest trend that may coincide with the crustal-scale dislocation Desailly Structure (Davis et al., 1998). In the eastern part of the province the intrusions follow a more northerly trend.

The intrusions in the area of the Watershed deposit are S-type syenogranites of the early Permian Whypalla Suite and occur in isolated beds that are incorporated in psammitic units.

Slate: This rock type comprises massive shale units and interbedded shale-siltstone units in which individual siltstone layers vary in thickness from 0.5 to 20 cm. The shale is composed of, dark-coloured, carbonaceous (graphitic), impure mudstone, usually preserving at least one, well-developed, penetrative foliation.

Slate-siltstone breccia: This is the main unit in the Watershed area and occurs along a 2 to 3 km wide zone that strikes north-northwest over a strike length of at least 20 km. The breccia is typically composed of isolated fragments of sandstone and siltstone (psammitic) set in a strongly foliated, dark-grey matrix of mudstone (slate), and represents the highly-deformed and transposed equivalent of the interlayered sandstone-siltstone-mudstone beds. Psammitic fragments make up between 10 and 90 vol.% of the rock mass, and vary in width from 0.5 to 5 cm. Fragments can be planar to linear in shape, and are locally strongly rodded to define an intense linear fabric. Some fragments preserve hook-like shapes resembling isolated fold hinges.

Chert: This rock type is restricted to the zones of slate-siltstone breccia and occurs as pods or layer-fragments of thinly-banded (0.5 to 30 cm), black to cream-grey siliceous rock with shale interlayers. The chert fragments are interpreted to be disrupted layers that were locally interbedded with the slate-siltstone-sandstone sequence.

Calc-silicate Conglomerate: The calc-silicate conglomerate unit is the principle host for scheelite mineralisation and its distribution is of critical importance when defining the ore zones. The unit consists of a clast-supported, polymeric conglomerate with rounded clasts from 3 to 30 cm (average 6 cm) set in a matrix of coarse sand- to grit. Clasts typically have a fine- to medium-grained, calc-silicate composition with carbonate, and vary from pale pink (garnet-rich), to pale-green (clinozoisite-rich), to pale grey (silicous). The matrix is green-grey and consists of quartz, clinozoisite, garnet, feldspar, and muscovite with minor carbonate, biotite, titanite, scheelite and pyrrhotite. The unit occurs as isolated pod-like bodies (i.e. boudins) and layer fragments, up to 15 cm in width and tens of metres in length, within psammitic and generally close to the contact with slate-siltstone breccia. Individual boudin segments range in size from a few centimetres to tens of metres, and may be layer-like, ovoid, irregular or wavy in shape.

Geology of the Watershed District

Sedimentary units

Sedimentary units around the Watershed deposit have undergone complex deformation and frequent disruption of bedding, similar to much of the Hodgkinson Province. The sequence of deformation events around the deposit has resulted in a transposition fabric characterised by a strongly developed linear fabric and several generations of overprinting folds. The intensity of the transposition fabrics is variable, from minor in psammitic-dominated sequences where primary layering can be preserved along significant strike-lengths, to intense in slate-dominated sequences in which the primary layering is completely destroyed. Due to the pervasive occurrence of high strain fabrics and transposition, it is difficult to define a type stratigraphic column for the Watershed area, more so because sedimentary structures are normally not preserved.

The main sedimentary units in the Watershed area are:

- Psammitic: A common rock type in the Watershed area, varying from quartzo-feldspathic greywacke to arkose, that locally preserves one or more foliations.
- Quartzite: A medium grained dark grey rock that constitutes only a minor portion of the sedimentary rock suite and occurs in isolated beds that are incorporated in psammitic units.
- Slate: This rock type comprises massive shale units and interbedded shale-siltstone units in which individual siltstone layers vary in thickness from 0.5 to 20 cm. The shale is composed of, dark-coloured, carbonaceous (graphitic), impure mudstone, usually preserving at least one, well-developed, penetrative foliation.

Figure 3. Generalised geological map of the Watershed deposit illustrating the influence of the regional fabric and transposition of the calc-silicate conglomerate (dark green).
Deformation events

The sedimentary rocks in the Watershed area are strongly deformed with intense folding and up to three penetrative foliations. The psammitic and calc-silicate conglomerate units occur as tectonic lenses in the form of boudins, boudin trails and layer segments enveloped by slate and slate-siltstone breccia units. These boudins are typically elongated with long axes plunging northwest at 20° to 50°. Primary layering (S₁) is generally destroyed, but is locally preserved within boudins of psammitic. The semi-continuous boudin trails of calc-silicate conglomerate also provide evidence for early layering in the area. The principle characteristics of each of the deformation events are summarised below.

D₃ and D₄ events: The earliest deformation events, referred to here as D₃, involved complete transposition of the primary layering as a result of at least two stages of upright isoclinal folding. Pre-existing sequences of alternating mudstone, siltstone and sandstone, together with the interbedded psammitic, chert and conglomerate units, were isoclinally folded and flattened to form the dominant, steeply southwest dipping foliation trend. The resultant fabric, S₁/S₂, is characterised by isolated, tight fold hinges, or fold limb segments defined by more competent lithologies (i.e. layer segments of siltstone and sandstone), enveloped in foliation domains dominated by slate, to form a typical high-strain transposition fabric. Fabric transposition probably happened repeatedly, given the complex, refolded fold shapes of some of the fold hinges, and D₃ and D₄, therefore, represent a progressive, composite set of events.

During the D₃ events the primary layering was tightly folded and boudinaged. Elongated lenses of more competent rock types within a matrix of slate can be observed on both an outcrop and regional scale. The competent psammitic and calc-silicate conglomerate units that host mineralisation, and occur as 10-100 cm scale lensoidal bodies, are also elongated parallel to the regional structural fabric. Feldspar phenocrysts in the outcropping granite exhibit a north-south alignment which may indicate the Koobaba granite was emplaced during D₃.

Granitic Dykes: Granite dykes are common in the vicinity of the Watershed deposit, and are both concordant and discordant with the main north-northwest trending S₁ fabric. Dykes crosscut D₃ to D₄ structures and generally show no evidence of internal ductile deformation; they appear to mostly post-date the D₃ shear zones. The dykes vary in width from 0.5 m to several tens of metres, and can be traced over strike lengths of tens to hundreds of metres. They are texturally variable, ranging from coarse porphyritic to fine-grained varieties. To the southeast of the Watershed deposit, biotite grains along the margin of a north-northwest trending granitic dyke (East Dyke) are oriented parallel to the mineral orientation (L₄) in a nearby D₃ shear zone, suggesting that at least some of the granite dykes were emplaced during D₄.

D₄ event: D₄ shear zones that cut and displace the dominant ductile fabric elements are common in the Watershed area. The shear zones are generally narrow (<10 cm), brittle-ductile fracture zones associated with minor veining along slickensided or striated fracture surfaces. Around the Watershed deposit, D₄ shear zones display a wide variety of orientations, with the dominant through-going structures being generally parallel to the main north-northwest to north trending ductile S₁ fabric. The shear zones are spatially associated with scheelite-bearing vein systems, with higher concentrations of veins apparent along the margins of the shears and near shear intersections.

Intrusive rocks

Granite plutons: Several intrusive bodies assigned to the Whypalla Supersuite crop out around the Watershed deposit. One of these, the Koobaba Granite, is exposed 3 km to the northeast of the Watershed deposit, occurring as elongated outcrops generally subparallel to the regional structural fabric. Feldspar phenocrysts in the outcropping granite exhibit a north-south alignment which may indicate the Koobaba granite was emplaced during D₃.

Andalusite porphyroblasts, up to 8 cm long, are common, especially to the south of the Watershed deposit. The andalusite grains overgrow D₁ to D₃ fabrics but are cut by scheelite-bearing veins and associated D₄ fractures, suggesting the andalusite probably formed in a contact metamorphic aureole above a pluton that must be close to surface, but is not exposed in the immediate vicinity of the Watershed deposit.

Deformed monzonite dykes: Monzonite dykes have only been observed in drill core. The dykes are less than 40 cm wide, dark to light-grey, and contain a foliation (S₅), indicating that they were deformed and emplaced early in the deformation history of the area. Locally, up to 10-15% of the rock consists of euhedral, deformed, partly resorbed and strongly fractured scheelite crystals, that occur associated with oligoclase. The scheelite crystals are locally crenulated in open fold shapes which, together with the internal foliation, suggests that the dykes were emplaced during D₃ to D₄.

Diorite: A small diorite body occurs about 2 km southeast of the Watershed deposit. In outcrop this body has a dyke-like appearance that parallels the East Dyke over a short distance. The diorite is cross-cut by thin quartz veins with minor scheelite.

Mineralisation

Tungsten mineralisation in the Watershed deposit occurs in the form of pure scheelite (CaWO₄). Scheelite occurs as disseminated crystals in monzonite dykes, and as stringers in calc-silicate conglomerate lenses, however, the bulk of the scheelite mineralisation occurs along the margins and in the alteration haloes of quartz-plagioclase veins that occur within lenses of calc-silicate conglomerate.
Scheelite in deformed monzonite dykes

Scheelite crystals up to 2 mm in diameter occur disseminated throughout monzonite dykes that have been intersected in drill holes. The scheelite crystals are subhedral to euhedral and are typically highly fractured. The crystals preserve complex growth zoning, dissolution lamellae and resorbed boundaries, suggesting partial recrystallisation during metamorphism. The scheelite also preserves ductile deformation features such as sigmoidal shapes, boudinage, and (D3) folding of trails of scheelite grains. Overall, the textures indicate that mineralisation formed during D3 or D2, and pre-dated Dc.

Disseminated scheelite in calc-silicate conglomerate

Scheelite is common but sparsely disseminated in calc-silicate conglomerate. The calc-silicate conglomerate units are generally massive, but preserve anastomosing fabrics that are mainly defined by composition bands of aligned clinzoisite and amphibole. Zoned, quartz-rich, patches with clinzoisite, garnet and feldspar, which formed within foliation domains at some time during D2 or D3, locally contain scheelite crystals that are aligned along the deformed fabric (S2 or S3), and preserve sigmoidal grain shapes indicative of dynamic recrystallisation and ductile deformation (Figure 4A).

Younger scheelite mineralisation associated with alteration zones near D2 shear zones and veins also occurs in calc-silicate conglomerate. Thin (<0.5 cm wide) quartz veinslets contain scheelite-quartz stringers (Fig. 4B), mainly where they cut garnet-rich clasts in the conglomerate, and disseminated scheelite grains occur along micro-fracture planes in calc-silicate conglomerate in the absence of quartz veins.

Scheelite veins in calc-silicate conglomerate and associated with D2 shear zones

Scheelite-bearing veins show a clear spatial association with D2 shear zones, and typically occur as sheeted vein swarms. The mineralised veins are largely restricted to calc-silicate conglomerate units, indicating that the host lithology asserted a critical control on the formation of scheelite in the veins. The veins generally terminate abruptly where they encounter slate units although, locally, veins may continue for several metres into slate. The veins are generally of limited (<30m) strike length, and vary in width from a few cm to 3m. The widest veins are tension veins with crystal growth at high angles to vein margins, that typically strike east-west and have a steep southerly dip. Veins in all other orientations are generally thinner (<10 cm), with crystal growth at lower angles or near-parallel to the vein walls, indicative of a shear component during vein opening and crystal growth. In some places along such veins, scheelite crystals have been broken and boudinaged along the long axis of the grains, i.e. parallel to the extension direction internal to the veins.

The association between D2 shears and mineralisation can be observed in a high-grade zone in the centre of the deposit, where mineralisation is concentrated along the zone of most intense fracturing and occurs along: northwestern trending fractures and veins; northeastern-trending quartz stringer zones; east-west trending veins; and as disseminations in the calc-silicate conglomerate. The east-west veins are only mineralised near D2 shear zones, with mineralised vein margins developed where the east-west veins occur within a several metre wide damage zone surrounding the shear zone.

Mineral Paragenesis

The peak prograde and retrograde mineral assemblages that formed in the calc-silicate conglomerate, and their association to scheelite mineralisation, were investigated to determine the effects of the complex deformation history on the distribution of scheelite.

Prograde mineral assemblages during D3 to D1

Garnet and quartz formed in the calc-silicate conglomerate from D3 through to D1. The garnet grains are euhedral, vary from fine- to coarse-grained, and can be subdivided into rimmed and un-rimmed garnets. The garnets are mainly grossular (Ca2+), with lesser spessartine (Mn2+) and almandine (Fe3+), and minor andradite (Fe5+). The rimmed garnets have complex textural and chemical zoning patterns, with spessartine-almandine-rich cores and an increase in grossular towards the rims. The cores of the rimmed garnets are interpreted to have formed during peak metamorphism (syn-D2) while the outer rims reflect retrograde conditions and probably formed during D1. In contrast, unrimmed garnets exhibit variable compositions in terms of mole % spessartine + almandine but display no zoning.

During D3 events both the un-rimmed and the cores of the rimmed garnets, along with quartz and actinolite, formed along the composite S1 foliation traces. Syn-D3 mineral growth in the calc-silicate conglomerate is characterised by garnet (GrAlm-SpPy-And-Dc), clinopyroxene (Di-Hd-Ps), quartz and minor titanite. The rims of the garnet cores are interpreted to have formed during D1 since they have a similar composition to garnet that overgrew boudinaged and broken up D3 garnets. The later syn-D3 garnets generally exhibit dissolution textures, and fracturing with quartz fracture fill and alignment along the L3 elongation lineation. Clinopyroxene occurs with syn-D3 garnet and quartz, and fine grained titanite occurs as an accessory phase typically intergrown with garnet.

Garnets in the calc-silicate conglomerate are commonly replaced and pseudomorphed by retrograde mineral assemblages (see below).

Retrograde mineral assemblages formed during D3

The prograde mineral assemblages in calc-silicate conglomerate that formed during D3 are totally or partially replaced by hydrous retrograde mineral assemblages. Three retrograde stages are recognised, and are interpreted to have formed during the shear related D3 events and associated vein infilling. The retrograde events are: early Retrograde stage 1; Retrograde stage 2; and late Retrograde stage 3. The relative timing of the retrograde stages was based on cross-cutting and overgrowth relationships observed in drill core and in thin section. It is important to define these retrograde stages because scheelite-rich veins opened in a multi-staged manner. The three retrograde vein assemblages are followed by a sulphide stage which developed in late fractures and veins.

Retrograde stage 1: This stage formed during the early stages of vein opening. Quartz and microcline (Ox100) formed in vein margins, accompanied by silicification in the immediate vicinity of the veins. This early microcline was overgrown by plagioclase (with An15-55), with quartz, clinzoisite and plagioclase growth in the adjacent wall rock. During this stage, plagioclase formed in vein margins, vein halos, and as a replacement phase in calc-silicate conglomerate.

Retrograde stage 2: This stage is associated with abundant scheelite growth and a shift to more sodic plagioclase compositions. The mineral assemblage in Retrograde stage 2 is characterised by intergrown plagioclase and scheelite, along with quartz and phlogopite near vein margins, and by clinzoisite, amphibole, plagioclase, phlogopite and scheelite in calc-silicate conglomerate (Fig. 5).

Scheelite in veins that formed during Retrograde stage 2 has variable textures and shapes. Scheelite crystals on the vein margins are generally less than 2 cm and formed in equilibrium with plagioclase. Larger scheelite crystals (up to 4 cm) locally occur in the central parts of veins and are commonly fractured and boudinaged, with quartz veins filling the interstitial space between scheelite fragments; i.e. deformation of the veins continued after scheelite growth. Locally, scheelite crystals remain intact and have grown as elongated crystals either perpendicular to the vein wall (e.g. in east-west striking veins), or at low angles to the vein wall (e.g. in northwest and northeast striking veins). In the calc-silicate wall rock, relatively Na-rich amphibole formed during the Retrograde stage 2 and replaced clinzoisite and clinopyroxene.

Retrograde stage 3: During Retrograde stage 3 there was further opening along the centres of the veins, with associated new growth of quartz, calcite, muscovite, and minor chlorite, tourmaline and fluorspar. The same assemblage, minus the tourmaline, also formed in the calc-silicate conglomerate. Irregular calcite stringers also cut the earlier retrograde assemblages in veins. Late during Retrograde stage 3, muscovite formed along the centre line of veins, cutting all earlier assemblages. Muscovite also occurs in the halos of mineralised veins where it replaces earlier phlogopite, while minor chlorite replaces amphibole in the calc-silicate conglomerate.

Figure 5. Scheelite-quartz-plagioclase on a D3 vein margin and halo, illustrating Retrograde stages 1 and 2.
Sulphide stage: A late sulphide event affected all rock types in the Watershed area and is expressed as pyrrhotite and arsenopyrite, with minor chalcopyrite and chalcocite, along fractures and in stringer veins. This event is not of economic significance, however it marks a shift from oxidised to reduced conditions.

**Dating Igneous Rocks and Alteration**

Zircons from a deformed, scheelite-bearing monzonite dyke yield an average age of ~350 Ma. This date provides a minimum age for the Hodgkinson Formation in the Watershed area, and constrains an early stage of igneous activity that occurred during peak-metamorphic, accretionary events (D1–2).

 heroine refers to referred are representative events of the Hodgkinson Formation along the northeast margin of the Australia Craton, and are the equivalent of D2 of Davis (1993) and Henderson et al. (2013), whilst our D1 is similar to D2 of Henderson et al. (2013).

2) D1 and later events, which are largely constrained to brittle-ductile shear zones, and associated with scheelite-bearing veins and retrograde alteration, or a regional metamorphic event at lower metamorphic grade. This group of D2 shear zones and veins provides a second-order, more localised control on the distribution of scheelite mineralisation, through the formation of mineralised shear zones and veins concentrated in the calc-silicate conglomerates.

The D2 events are associated with extension and granite emplacement between 281–271 Ma and coincide with the main stage of tungsten mineralisation. These events correlate with the regional D3 events associated with Permian granite emplacement and extension (Davis and Henderson, 1999), in a volcanic arc setting, and coincide with the onset of opening of the Bowen Basin (to the south) in a back-arc setting.

**Discussion**

Deformation and metamorphic events that influence the distribution of scheelite mineralisation in the Watershed area can be sub-divided into two groups:

1) Progressive D1 to D3 events characterised by intense deformation and peak metamorphism, which resulted in nearly one, if not two stage(s) of complete transposition, of the existing foliations: the Fiery Creek Slate Belt, North Queensland: Tectonophysics, v. 224, p. 337-362.

2) Late mineralisation that is more widespread than the early scheelite, and formed in around 275 Ma during D3, extensional deformation and vein formation, in a mechanism that is similar to that described for lode-gold deposits (e.g. Cox et al., 1995; Groves et al., 2003; Goldfarb et al., 2005; Diks et al., 2013), and in which the source of the fluids may be metamorphic, igneous or a mixture of both.

We propose that the economic scheelite mineralisation formed during D3, and resulted from a hydrothermal up-grade (or physicochemical) tungsten enrichment in the Watershed area.

This research project was part of the first author’s PhD research project at JCU, and was collaborative regional project with the Geological Survey of Queensland (GSQ). The GSQ funded the analytical work and Vital Metals Ltd provided logistical support at the Watershed camp during the field campaigns.

**References**


Vale Pat Williams

Geologist, Mountaineer, Footballer, EGRU Director

Patrick John Williams died July 6, 2018, at the age of 61. He passed away peacefully and surrounded by friends and family, on the Isle of Anglesey, UK, following a six year battle with cancer.

Pat was born March 14th 1957 in Widnes, Cheshire, UK, and obtained a BSc Geology from the University of Liverpool in 1978. During the same year he started his PhD at the University of Southampton with the then newly established economic geology research group under the supervision and leadership of Dr Nick Badham. His research focused on metamorphosed massive sulphide deposits in north-west Spain. Following the award of his PhD in 1982 he took up a lectureship position at Goldsmiths College, University of London, and during his seven year tenure was promoted to Senior Lecturer. It was in 1991 when Pat's career began to have international impact, following a move to James Cook University (JCU) in Townsville. Pat was a founding member of the new Key Centre in Economic Geology, and he became the cornerstone for a new period of growth in ideas, graduate students and interaction with the minerals industry. JCU was one of the first universities in Australia to establish strong academic-minerals industry collaboration through the Economic Geology Research Unit (EGRU). Pat helped cement the organization of EGRU and the support of School and School of Geology activities in general. In addition, he made a major contribution to undergraduate teaching in mineralogy, petrology and economic geology.

His consulting career began in 2009, as Director of Clump Mountain Geoscience, and included major clients such as MMG and OZ Minerals. During his time as a consultant Pat maintained his reputation for diligence and professionalism, continued his interest in IOCG deposits, and made notable contributions to the understanding of the Prominent Hill deposit in South Australia.

In addition to a passion for geoscience, Pat's interests included hiking and mountaineering, particularly in the Munros of Scotland (mountains over 3000ft). He included hiking and mountaineering, particularly in the Munros of Scotland (mountains over 3000ft). He was an avid appreciator of red wine whether it was Friday afternoon Earth Sciences Wine Club, which led to whisky at times, or gatherings of the Hydrothermal Fluids Society at international conferences. He embraced all of his passions in the greater context of the geological community conversation, and he revelled in that space.

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To his friends and colleagues, Pat was a model for numerous subsequent Townsville-based international ore deposit conferences. Pat continued working on IOCG deposits throughout his academic career, leading a major research project on hydrothermal fluids in the Predictive Mineral Discovery CRC from 2001 to 2005. Pat’s work, and that of his colleagues and students, was prolific, but he always kept a low profile. He developed a special fondness for the Cloncurry District in one of the hottest parts of Australia. Once, when he asked “Is it always this hot in northern Queensland?” and the response was “Yes”, he reputedly replied “Good, I’ll stay here”.

Pat’s contribution to the understanding of IOCG deposits, and the geology of the Cloncurry region, was widely recognised. His early research was captured in a special issue of Economic Geology in 1998, of which he was guest editor, that focussed on the Mount Isa-Cloncurry region. In 2005 he was a lead author for the landmark 100th Anniversary Economic Geology Volume, with a paper entitled “Iron Oxide Copper-Gold Deposits: Geology, Space-Time Distribution, and Possible Modes of Origin”. Pat also had great editorial skills which led to his appointment as editor of Mineralium Deposita from 2008 to 2012.

Pat was also recognized for his mentorship and student supervision, and was instrumental in establishing the first Student Chapter of the Society of Economic Geologists in the Southern Hemisphere in 1993. He was committed to his students and provided opportunities for them to realize their potential in the field of ore deposit studies at an early stage. Many of those students have gone on to highly successful careers in the research, minerals and financial sectors.

Pat’s involvement with EGRU activities was extensive, including initiating collaborative internal reviews of EGRU on an annual basis, and acting as Director for two years. He was also much valued as an academic colleague – excellent counsel, supportive of group activities, and invariably reliable in delivery of the tasks on his plate. His peers enjoyed his gruff laughter and disdain of unnecessary administrative procedures, and yet he took on those tasks most important to the organization of EGRU and the support of School activities in general.

In addition, he made a major contribution to undergraduate teaching in mineralogy, petrology and economic geology.

His consulting career began in 2009, as Director of Clump Mountain Geoscience, and included major clients such as MMG and OZ Minerals. During his time as a consultant Pat maintained his reputation for diligence and professionalism, continued his interest in IOCG deposits, and made notable contributions to the understanding of the Prominent Hill deposit in South Australia.

In addition to a passion for geoscience, Pat’s interests included hiking and mountaineering, particularly in the Munros of Scotland (mountains over 3000ft). He completed all 282 Munros. Most of them he did alone, some of them twice or even three times, in different seasons, and/or by different routes to the summits. The first 56 he did while living in the UK, the rest were done while living in Australia, and required a great deal of commitment and determination. In some cases he climbed two or even three in one 24 hour period, which required a solo wild bivy or two, often in fierce weather with minimal gear and no comforts. The Cuillin Ridge on Skye was his favourite mountain. He did his final one, Ben Vorlich, in 2012.

Pat’s choice of undergraduate university was no coincidence, and due to his love of Liverpool FC. He played football with both skill and commitment in the Over-35 league in Townsville for more than 20 years (with a broken leg for efforts on one occasion) and represented the Townsville Has Beens right up until May this year.

Pat, in keeping with his broader enjoyment of his career, was an avid appreciator of red wine whether it was Friday afternoon Earth Sciences Wine Club, which led to whisky at times, or gatherings of the Hydrothermal Fluids Society at international conferences. He embraced all of his passions in the greater context of the geological community conversation, and he revelled in that space.

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Pat will be missed by the economic geology community in Australia and beyond, his many friends in North Queensland, his partner Cheryl Robertson, and family in the UK.

Tim Baker, Cheryl Robertson, Lucy Chapman, Bob Henderson, Nick Oliver
Postgraduate Student Research Projects

Helge Behnsen (PhD)
Magma fertility related to Au-Cu mineralization in north Queensland, Australia - evaluating the potential for linked porphyry Cu±Au (±Mo) deposits at depth.
Supervisors: A/Prof. Carl Spandler, Prof. Paul Dirks

Tegan Beveridge (PhD)
Geochemical characterisation of bentonites combined with high-precision geochronology for correlation and provenance in the Cretaceous Strata of North America.
Supervisors: A/Prof. Eric Roberts, A/Prof. Carl Spandler

Alex Brown (PhD)
Base Metal Genesis, Stratigraphy and Structural Evolution of the Central Tommy Creek Domain, Mt Isa Inlier.
Supervisors: A/Prof. Carl Spandler, Prof. Tom Blenkinsop, Prof. Paul Dirks

Michael Calder (PhD)
Zonation, paragenesis and fluid evolution from the root to top of the Far Southeast Lepanto porphyry epithermal system, Mankayan district, Philippines.
Supervisors: Prof. Zhaoshan Chang, A/Prof. Carl Spandler

Robert Coleman (PhD)
Evolution of the Tommy Creek Domain and associated rare earth mineralisation.
Supervisors: A/Prof. Carl Spandler, Prof. Paul Dirks

Elliot Foley (PhD)
Jurassic Arc - Reconstructing the Lost World of Eastern Australia through basin analysis in the Laura and Carpentaria Basins, NE QLD.
Supervisors: A/Prof. Eric Roberts, Dr Espen Knutsen, A/Prof. Carl Spandler

Kelly Heilbron (PhD)
Establishing a tectonic framework for the Cretaceous break-up of eastern Gondwana.
Supervisors: Dr James Daniell, Dr Rob Holm, A/Prof. Carl Spandler, A/Prof. Eric Roberts

Leigh Lawrence (PhD)
Geochronological investigation of Oligocene-aged volcanic events in the Rukwa Rift Basin, southwestern Tanzania.
Supervisors: A/Prof. Carl Spandler, A/Prof. Eric Roberts

Xuan Truong Le (PhD)
The Tick Hill gold deposit, Mt Isa Inlier
Supervisors: Prof. Paul Dirks, Dr Ioan Sanislav, Dr Jan Martin Huizenga

Asish Mishra (PhD)
Rates of Erosion and Weathering in the Tropics.
Supervisor: Dr Christa Placzek, Prof. Michael Bird

Teimoor Nazari-Dehkordi (PhD)
The origin and evolution of heavy rare earth element mineralisation in the Browns Range area, Northern Australia.
Supervisors: A/Prof. Carl Spandler, Prof. Nick Oliver, Prof. Paul Dirks

Theresa Orr (PhD)
Paleoenvironmental and Paleoclimatic Analysis of Selected Cretaceous, Oligocene and Miocene Palaeosols from the Rukwa Rift Basin, Tanzania
Supervisors: A/Prof. Eric Roberts, Prof. Michael Bird, Dr Chris Wuster

Prince Owusu Agymang (PhD)
Mesozoic detrital zircon provenance of Central Africa: implications for Jurassic-Cretaceous tectonics, paleogeography and landscape evolution.
Supervisors: A/Prof. Eric Roberts, A/Prof. Carl Spandler, Dr Rob Holm

Alexander Parker (PhD)
Fluids in the lower crust: storage and mobilization.
Supervisors: Dr Jan Martin Huizenga, Dr Ioan Sanislav

Jaime Poblete Alvarado (PhD)
Geochemical characteristics and origin of the Watershed W Deposit, North Queensland, Australia.
Supervisors: Prof. Zhaoshan Chang, Prof. Paul Dirks, Dr Jan Martin Huizenga

Caleb Puszkiewicz (PhD)
Analyses of JCU Groundwater-Ocean Interconnection, Extent and Potential Impacts
Supervisors: Dr Christa Placzek, Dr han She Lim, Dr Bithin Datta

Jessie Robbins (PhD)
Understanding the genesis and patterns of cave fill across the Cradle of Humankind, South Africa.
Supervisors: Prof. Paul Dirks, A/Prof. Eric Roberts

David Rubenach (MSc)
Earthquake hazard mapping and modelling to support Qld Rail’s infrastructure.
Supervisors: Dr James Daniell, Prof. Paul Dirks

Fredrik Sahlström (PhD)
Mt Carlton high-sulphidation epithermal deposit, Queensland Australia: Geological characteristics, genesis and implications for exploration.
Supervisors: Prof. Zhaoshan Chang, Prof. Paul Dirks

Paul Slezk (PhD)
Evolution and origin of the Gifford Creek Carbonatite Complex: understanding rare earth element mobility in the continental crust.
Supervisor: A/Prof. Carl Spandler

Christopher Todd (PhD)
Sedimentary history of the Porcupine Gorge National Park and application of U-Pb detrital zircon geochronology for correlation of Cretaceous and Jurassic strata in northern Queensland.
Supervisor: A/Prof. Eric Roberts, A/Prof. Carl Spandler

Joshua Spence (PhD)
Magma Fertility of the Mary Kathleen Fold Belt (MKFB), Mt Isa Inlier
Supervisors: Dr Ioan Sanislav, Prof. Paul Dirks, A/Prof. Carl Spandler

Michal Wenderlich (PhD)
Seismic Stratigraphy of the Great Barrier Reef.
Supervisor: Dr James Daniell

Jelle Wiersma (PhD)
Cave sedimentation processes, geochronology, and the distribution of hominins at Rising Star Cave, Cradle of Humankind, South Africa.
Supervisors: A/Prof. Eric Roberts, Prof. Paul Dirks

Matthew Van Ryt (PhD)
Geochemical characterisation of gold mineralisation in Geita Hill, Geita Greenstone Belt, Tanzania.
Supervisors: Dr Ioan Sanislav, Prof. Paul Dirks, A/Prof. Carl Spandler

Christopher Yule (PhD)
The structure and stratigraphy of the offshore Canning Basin.
Supervisor: Dr James Daniell
The first international conference dedicated to the availability of resources needed to sustain future generations, with particular sessions on energy, minerals, water, and education and knowledge, was held at the Vancouver Convention Centre, Vancouver, Canada from 16 to 21 June, 2018. The conference, organized by the International Union of Geological Sciences and several predominantly Canadian earth science associations (CFES, CIM, GAC, and MAC), attracted almost 2000 participants from across the globe. Along with several others from EGRU, I attended the conference and gave a presentation on rare earth element mineralisation in northern Australia, under a sub-theme focusing exclusively on “Rare Earth Elements, Lithium and Related Advanced Materials”. In the following days, I had the opportunity to catch up with some of the well-known experts in the field of REE geology. Almost everyone believed that to secure a steady production of highly sought REE, exploration techniques must focus on new styles of ore formation such as recently-identified sedimentary-hosted ores rather than the traditional magmatic-hosted ores (see article on page 9 of this newsletter).

The six day conference offered several interesting talks and discussion panels on some critical elements, particularly REE, Li, U and Th. As each theme had multiple parallel sessions I was able to attend only a limited number of interesting talks. Despite this, the latest findings further demonstrated that Australia indeed contains significant resources of highly sought critical elements, highlighting its role in supplying raw materials to high-tech industries. Currently, Australia is host to a significant portion of the known U resources, and also has a potential to become one of the major REE producers. Innovatively, the RFG 2018 conference devoted one theme to “Education and Knowledge” through which school teachers and professional geologists from industry and academia were brought together. During this get-together some new and effective ways of teaching different aspects of geology to school students were discussed. One new popular method was introduced by Carl Spandler, and employs playing cards known as “Mineral Supertrumps” to assist learning of mineralogy. Another interesting talk detailed the outcome of the “EUROCORE” (European Core Sample Collection for Master Training) project to create teaching modules for students through providing schools with representative drill core samples.

This conference also provided a great opportunity to visit the unlimited natural and artificial beauties of Vancouver and covering multiple Canadian Cordillera terranes including the Coast Belt, Intermontane Belt, and Omineca Belt. The Upper Fir carbonatite-hosted Nb-Ta deposit contains 53.8 Mt of 0.163% Nb2O5 & 0.0196% Ta2O5 (indicated + inferred) and is owned by Commerce Resources. It is located in the Monashee Mountains in the Omineca Belt of BC, and comprises dolomite (with minor calcite) carbonatite dykes that intrude the Proterozoic to Paleozoic amphibole-grade metasedimentary rocks. The main ore minerals are pyrochlore and columbite (Rukhlov et al., 2018). The field trip was an excellent example of carbonatite-dyke hosted critical metal deposits, providing valuable comparisons to my own study of the Yangibana LREE district, a carbonatite-phoscorite-associated REE deposit in which mineralisation is hosted in monazite in a series of dykes. In addition to the plethora of data provided by the BCGS, I also gained some new friends with shared interests in the weird world of carbonatites.
Mineral Systems field trip
Cloncurry Region, July 2018
Teimoor Nazari-Dehkordi
Postgraduate Student, EGRU JCU Geoscience

The Economic Geology Research Centre (EGRU) organised a four day field trip, from 24th to 27th July, to the Mt Isa Inlier. The field trip attracted more than 40 industry, government and research geologists and included visits to open pits, examination of drill core, and a number of presentations. The pleasantly mild weather allowed the field trip to proceed as planned.

The first day started with a brief early morning catch-up, prior to driving to the base metal deposits located within 100 to 200 km south of Cloncurry. The first stop included a visit to mineralised outcrops at Kuridala where host rocks to mineralised veins mainly consist of low-grade metamorphic rocks (schist and phyllite), complimented with a short visit to the historical mining site where rusted smelters and other 19th century mining facilities were silently speaking of the long history of mining in the area (Photos 1, 2). The second stop was at the Mt Elliott and Swan Cu-Au deposits which are associated with carbonaceous metapelite (CMP), schists and trachyandesite. A lunch break at the Chinova camp near the Merlin deposit was followed by a short scavenger through the Little Wizard stock pile in search of Mo ore samples. The afternoon was spent mainly looking at drill core from the Mt Elliott, Mount Dore and Swan deposits at the exploration core yard (Photo 3), before heading to the Osborne Village where Chinova generously provided accommodation and a BBQ for field trip delegates.

The second day began with a presentation by Mark McGeogh from Chinova on the Selwyn Mineral Field, with particular emphasis on geology of the Osborne Cu-Au deposit, located to the south of the Mt Elliott and Swan deposits. Delegates were then trucked to view the excellent exposures in the main open pit of the Osborne deposit (Photos 4, 5), where the orebody is mostly hosted within metasedimentary rocks of the Soldiers Cap Group, and occurs associated with iron formation, and trachyandesite. A lunch break at the Chinova camp near the Little Wizard stock pile was followed by a short scavenger through the Little Wizard stock pile in search of Mo ore samples. The afternoon was spent mainly looking at drill core from several holes was laid out for viewing in the afternoon.

Delegates then headed to the Osborne core shed to view drill core from the Osborne and Kulthor deposits. After lunch, a visit to the Victoria Cu mine north of the Osborne deposit provided an opportunity to view some of the mineralisation, which is hosted within black shales and consists largely of chrysocolla and azurite, with subordinate malachite and secondary native copper (Photo 7). The visit to the Victoria pit, now filled with water, also provided (some) delegates with the chance to demonstrate their rock-throwing skills.

On the third day delegates loaded into vehicles for the two-hour drive to the Cannington Ag-Pb-Zn mine, north east of the Osborne deposit, and 135 km SSE of Cloncurry. Upon arrival presentations by Lucy Jones and Tony Webster from South32 provided significant information about the nature of the crudely stratabound mineralisation at Cannington, which is hosted largely by a sequence of migmatic biotite-sillimanite-garnet-bearing quartzofeldspathic gneiss. The main sulphides include galena and sphalerite with minor pyrite, chalcopyrite and local pyrite. Drill core from several holes was laid out for viewing in the afternoon.

The Cannington deposit, very rich in Ag-Pb-Zn, is rather unusual compared to nearby deposits which are dominantly Cu-Au rich. The timing of the mineralisation at the Cannington (~1650 Ma) appears to slightly predate that of the Cu-Au ore deposits in the area (e.g. Osborne ~1600 Ma, Mount Elliot ~1510 Ma) but all of these ages broadly coincide with the Isan Orogeny during which the North Australian Craton and Laurentia (eastern North America) were assembled.

The fourth and last day of the trip included two short stops on the way to Cloncurry: one stop at the breccia outcrops about 20 km south east of Cloncurry and another at the Mary Kathleen U deposit about 45 km to the west of Cloncurry. The once strategically-important and now touristically-attractive Mary Kathleen deposit was one of the major U producers in Australia, operating from 1954 until its closure in 1982. The uranium and rare earth element ore was accommodated within the garnet-bearing calc-silicates within the Corella Formation of the Mary Kathleen Group. Visiting the Mary Kathleen deposit and its strangely-beautiful peacock-coloured lake at the open pit marked the end of the field trip (Photo 8).
The Mt Leyshon gold-silver open-pit mine operated from 1987 to 2002, producing over 2.5 million ounces of gold and 2.3 million ounces of silver\(^1\). Rehabilitation commenced in 2002. The site is now owned by Newmont, Australia, and is in the post closure and maintenance/monitoring stage.

In early September, students in JCU’s Minesite Rehabilitation subject (EA3005) gained a first hand perspective on environmental remediation efforts during a field trip to Mt. Leyshon. The aim of this subject is to introduce students to simple management strategies of mine waters and mine waste materials, provide students a general background on current rehabilitation measures, further understanding of the applicability of geochemistry in delineating minesite pollution problems, and illustrate the diversity of mining operations and the site specific environmental challenges associated with them. This subject has specific content focused on erosion control, acid mine drainage and the use of cyanide in gold processing, and these topics were the specific focus of this field trip.

The students spent most of the day onsite and had a general overview of the site. Students then observed a number of surface water and groundwater monitoring locations, historic mine workings, stream sediment monitoring locations, and several dams/tailings ponds. A recent/ongoing earthworks projects aimed at erosion control on the waste rock dump was also observed.

Thank you to Newmont and to David Young (Closure Superintendent) for hosting our students.

\(^1\)http://leyshonresources.com/projects

Above: Examination of recent erosion control efforts on the waste rock dump.

Right: Taking the pH of water draining from tailings.
EGRU Professional Geologist Short Courses in 2019

Ore Textures and Breccias Recognition Techniques
28 - 30 January 2019
Course Leader: Dr Gavin Clarke, EGRU JCU
This three-day course covers the fundamentals of textural observation and interpretation in mineralised hydrothermal systems. The techniques used are simple, highly effective and require no specialised equipment for their implementation. The techniques are also extremely practical in that they generate numerous questions concerning the mineralisation being studied and commonly provide vectors toward mineralisation for drill testing. Critical evaluation factors considered during the course include:
- Infill: Recognition Criteria
- Alteration: Recognition & Evaluation
- Channelways: Recognition Criteria
- Overprinting and Paragenetic: Recognition & Sequencing Criteria
- Breccia: Recognition Criteria
- Breccia: Rudimentary Classification system
- Tectonic Breccia Systems
- Intrusive Breccia Systems
- Paragenetic Core Logging

Core Logging Techniques
31 January - 1 February 2019
Course Leader: Prof. Paul Dirks, EGRU JCU
This two-day course introduces the basic skills and methodology required to review and log geological core. Emphasis is placed on the recognition, description and acquisition of oriented data (bedding planes, faults, fractures, shear zones), and how this data relates to field observations. The course aims to familiarise participants with the key requirements of core logging, and how to interpret and integrate drill logs with geological models.

The course will comprise short morning lectures introducing the principles of core logging on day one and the integration of core logs into structural sections and geological models on day two, with substantive time each day spent undertaking practical group exercises.
Day 1 - Logging at suitable scales to capture the required degree of information for a successful interpretation, and, importantly, present that data and interpretation to their peers.
Day 2 - Construct cross sections from existing core logs, orientation data and geological maps. This will require careful consideration of how to connect critical markers to best reflect the geology of the area. Results will be discussed within the group at the end of the practical sessions.

QAQC for Mineral Exploration & Beyond
2 February 2019
Course Leader: Dr Dennis Arne, CSA Global
This one-day short course is designed to present a clear and practical approach to designing, implementing and assessing QAQC protocols for exploration and drilling programs. It will involve a series of practical exercises that will allow the participants to develop confidence in plotting and assessing quality control data using real-world data. Emphasis will be placed on using quality control data to reduce ambiguities associated with the interpretation of exploration results and to help minimise errors in resource estimates. Topics covered will include:
- Meeting the requirements of reporting codes & regulators
- Implications for exploration and resource estimation
- Representative sampling and data precision from field to instrument
- Selection of certified reference materials (CRM)
- Check Assays and Blanks – when, where and how
- In-house laboratory quality control data
- Quality control for additional data sets: e.g. bulk density, collar and down-hole surveys
- Reference material control plots
- Estimates of data precision
- Acceptable carry-over vs cross contamination
- Quality control failure
- Tracking issues, actions and outcomes
- Database structure
- Data verification
- Integration of quality control data

Dennis Arne has over 35 years’ experience as a geologist and geochemist, working in a wide range of commodities and environments. In recent years he has consulted to exploration programs for precious and base metals exploration in Australia, North America, South America and the Middle East. This has included the design and implementation of geochemical surveys, the interpretation of geochemical data, the design of QAQC programs, reviews of geochemical data quality, and training of personnel. He has published extensively in the areas of applied geochemistry and economic geology.

Integrating Geochemistry & Mineralogy for Exploration
3 February 2019
Course Leader: Dr Dennis Arne, CSA Global
(Delegate numbers are limited)
Geochemical and mineralogical data are now routinely collected on the same sample material, but the interpretation of these data sets is often done separately. Geochemical data may include assays or multi-element data collected from crushed rock or from surficial material. Mineralogical data may include hyperspectral analyses, semi-quantitative XRD or heavy mineral separates. Integration of complementary data sets such as these on a single interpretive platform allows for a better understanding of geochemical and mineralogical processes associated with hydrothermal mineralisation and secondary dispersion.
The short course will be a full day of lectures, discussions, and practical interpretive exercises. Participants will need to bring a laptop computer and download a demonstration copy of ioGAS software. Lectures on geochemical and mineralogical responses from some common hydrothermal deposit types will be integrated with exercises involving data interpretation. Topics covered will include:
- Introduction to the integration of geochemical and mineralogical data
- Introduction to exploration data analysis (exercise)
- Review of hydrothermal alteration systems
- Defining hydrothermal alteration using geochemical data (exercise)
- Introduction to mineralogical data in mineral exploration
- Case studies illustrating data integration
- Data integration exercises

EGRU News September 2018
Management in Mineral Exploration
February 2019
Course Leader: Dr Nick Franey, NJF Consulting
Five one day modules are offered as individual courses.
Most of these courses are suited to both technical and non-technical professionals involved in exploration management.

Monday 4 February
The Principles and Key Success Criteria of Mineral Exploration Management

Tuesday 5 February
Day-to-Day Management for Mineral Exploration

Wednesday 6 February
Data Management for Mineral Exploration and Feasibility Studies

Thursday 7 February
The Non-Technical Aspects of Mineral Exploration Management (e.g. HR, Administration, Logistics, HSEC)

Friday 8 February
Financial Aspects of Mineral Exploration and Project Evaluation (for experienced geologists)

Nick Franey has taught the Business and Financial Management module of the JCU Masters of Mineral Geoscience (MGM) since 2016, working with Andy White until Andy retired (see EGRU Newsletter April 2018 for Nick’s profile). In response to feedback from industry, Nick has now developed a series of one-day courses based on the MGM course, to provide a flexible option for time-poor explorers who are looking to enhance their management skills.

QGIS for Geologists
9 February 2019
Course Leader: Mr Grant Boxer, Consultant Geologist
(Delegate numbers are limited. The course will also be offered on 10 February if there is sufficient demand.)
QGIS is a free open-source GIS program that runs on the PC, Mac and Linux. Although QGIS is not specifically built for geological applications, the program is very capable and can do the majority of data import, data display and map production required by today’s geologists. A wide variety of geological symbols and patterns are available for decorating geological maps.
This workshop is designed for both new and experienced users of Geographic Information Systems. The workshop includes an introduction to the various features of QGIS and extensive hands-on sessions using QGIS to create maps, and to explain and demonstrate how to import and display various types of data (vector, raster, geological, geochemical, geophysical, and satellite imagery).
Registrants will use their own laptops during the course and will be requested to download and install the latest version of QGIS, together with a number of free plug-ins, before the workshop. GIS data will be provided for the hands-on workshop together with documentation on using QGIS in mineral exploration. Grant Boxer, a consultant geologist with over 40 years' experience in exploration and mining, has presented over standards, recommendations and guidelines to assist geologists, mining engineers and other technical staff to establish sound processes for data collection; quality control and assurance; analysis; interpretation and estimation of Exploration Targets, Mineral Resources and Ore Reserves; and reporting of all of these activities. The Checklist of Assessment and Reporting Criteria (Table 1) is a valuable tool for all technical staff contributing to exploration and mining. It will also introduce the concept of the Competent Person.

The JORC Code: For technical and non-technical professionals
This half-day course is designed for anyone new to the JORC Code, including early career geoscientists, and geoscience and engineering students considering a career in the resources industry. Other technical and non-technical professionals who wish to develop an understanding of the Code are also welcome to attend.
The course will provide an overview of the Code and illustrate how Table 1 can be used to guide day-to-day work flows and procedures in exploration and mining. It will also introduce the concept of the Competent Person.

Technical staff signing off on public reports presenting Exploration Results, Mineral Resources and Ore Reserves are accepting significant personal responsibility for these reports. This course is designed as a refresher for technical staff who are currently taking Competent Person responsibility for public reporting of Exploration Results, Mineral Resources and Ore Reserves; or those that may be in a position to do so now or in the near future.
The course will provide an overview of the key elements of the Code and how it is monitored, focusing on the issues most relevant to Competent Person responsibility. Case studies will be used to illustrate good reporting practices.

The JORC Code: An Introduction & A Refresher
11 February 2019, 2 x half-day courses
Course Leader: Mr Mark Berry, Derisk Geomining
The JORC Code sets out the requirements for public reporting of exploration and mining information, however its scope is much broader than this. It sets out standards, recommendations and guidelines to assist geologists, mining engineers and other technical staff to establish sound processes for data collection; quality control and assurance; analysis; interpretation and estimation of Exploration Targets, Mineral Resources and Ore Reserves; and reporting of all of these activities. The Checklist of Assessment and Reporting Criteria (Table 1) is a valuable tool for all technical staff contributing to exploration and mining, from new graduates to experienced veterans.

Introduction to the JORC Code
12 February 2019
Course Leader: Mr Mark Berry, Derisk Geomining
This workshop is aimed at geologists and other mining industry professionals. No prior knowledge is assumed.
Geologists provide essential technical information during all stages of exploration, feasibility, development and mine operations. Much of this information is used by mining engineers, metallurgists, environmental staff, operations staff and mine management for planning and operations management. But, almost everything geologists deliver to these staff are estimates and interpretations rather than FACTS, so how do geologists identify, document and convey the fundamental uncertainties associated with their estimates and interpretations to non-geologists? This workshop will review the sources of geological uncertainty that feed into exploration, mineral resource and ore reserve estimates, mine planning, scheduling, optimisation and operations – with implications from pit to port. Workshop modules include:
- Risks and opportunities linked to the provision of geological information
- Conventional risk assessment and management systems
- Contributions to geological uncertainty
- Approaches for identifying, documenting and communicating geological uncertainty to non-geologists

Case studies emphasising the importance of assessing geological uncertainty linked to mineral resource and ore reserve estimates (including mining, processing, waste disposal and transport) are used to emphasise the importance of effectively managing geological risk. Group interaction and exercises are also used to illustrate and reinforce workshop concepts.

Mark Berry is a geologist with over 38 years’ experience, spanning exploration, feasibility and development, mine operations, management, research and development, consulting, and professional development.
Advanced Field Training

29 June - 6 July 2019
Course Leaders: Prof. Paul Dirks, Dr Ioan Sanislav
Location: Cloncurry-Mt Isa area, NW Queensland

This intensive 8-day field course is designed to provide geoscientists with essential exploration-related field skills in complexly deformed and altered rocks. Real field mapping is a dying art and this course does not encourage wandering around with a GPS making random observations. Genuine ‘form surface’ mapping of contacts, alteration zones and structures will be integrated with paragenesis, geophysical interpretation and the use of alternate knowledge-based and data-based exploration models. The course will also include an introduction to the simple and useful application of semi-quantitative prospectivity tools.

The field course will cover:
- Veins, breccias, shear zones, paragenesis, overprinting, geometry
- Advanced structural geology and structural controls
- Developing exploration strategies from field observations

Photos, top to bottom, courtesy of: Yanbo Cheng, Robbie Coleman (x2), Yanbo Cheng, Robbie Coleman, EGRU JCU.
Sn-W-Critical Metals & Associated Magmatic Systems

A geological conference with a session in honour of Dr Roger Taylor

The Economic Geology Research Centre (EGRU) at James Cook University is proud to announce a conference on “Sn-W-Critical Metals & Associated Magmatic Systems” to be held in the historic Herberton tin field in north eastern Australia, 24-28 June 2019. The conference will include a session in honour of former EGRU Director, Dr Roger Taylor, in recognition of his contribution to the understanding of Sn magmatic systems in Australia, and globally.

The conference will address advances and breakthroughs in understanding the setting, genesis and characteristics of magmatic systems related to Sn-W-Critical Metal mineralisation, including Rare Metal Pegmatites. The conference program will feature presentations from world-class researchers in the field, including:
- Prof. Rolf Romer (GFZ, Potsdam, Germany)
- Prof. Jingwen Mao (Chinese Academy of Geological Sciences, Beijing, China)
- Prof. Shao-Yong Jiang (China University of Geosciences, Wuhan, China)
- Dr Phillip Blevin (Mineral Systems, Geological Survey of NSW, Maitland, Australia)
- Prof. Zhaoshan Chang (Colorado School of Mines, Denver, USA)
- Prof. David Cooke (CODES, University of Tasmania, Hobart, Australia)
- Dr Peter Pollard (Pollard Geological Services, Brisbane, Australia)
- Dr Yanbo Cheng (EGRU, James Cook University, Townsville, Australia)

EGRU warmly welcomes academic, industry and government colleagues, including students and young professionals, to join us at the conference and take part in discussions while enjoying the glorious setting of the Atherton Tablelands in tropical far north Queensland.

Abstract submission will open later this year.

Preliminary Conference Timetable
(subject to change)

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<th>Date</th>
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<tr>
<td>24 June</td>
<td>Monday evening welcome function</td>
</tr>
<tr>
<td>25-27 June</td>
<td>Technical Presentations (includes half-day field trip to the historic Herberton township and tin field)</td>
</tr>
<tr>
<td>28 June</td>
<td>Optional 1 to 1.5 day Field Trip</td>
</tr>
</tbody>
</table>

For further information please contact the conference conveners:
- Carl Spandler: carl.spandler@jcu.edu.au
- Yanbo Cheng: yanbo.cheng1@jcu.edu.au
- Kaylene Camuti: kaylene.camuti@jcu.edu.au
- Jan Huizenga: jan.huizenga@jcu.edu.au

or contact the EGRU Administration Officer
- Judy Botting: judith.botting@jcu.edu.au

For information on EGRU analytical services contact A/Prof. Carl Spandler: carl.spandler@jcu.edu.au
EGRU Members receive discounted registration for EGRU conferences, short courses and workshops.

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Delegates attending EGRU conferences, short courses and workshops may earn Professional Development points from their professional bodies.

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- Core Logging
- QAQC
- Exploration Geochemistry & Mineralogy
- Mineral Exploration Management
- QGIS for Geologists
- The JORC Code
- Geological Risk & Uncertainty
- Advanced Field Training

Details in this issue: pages 35 - 40